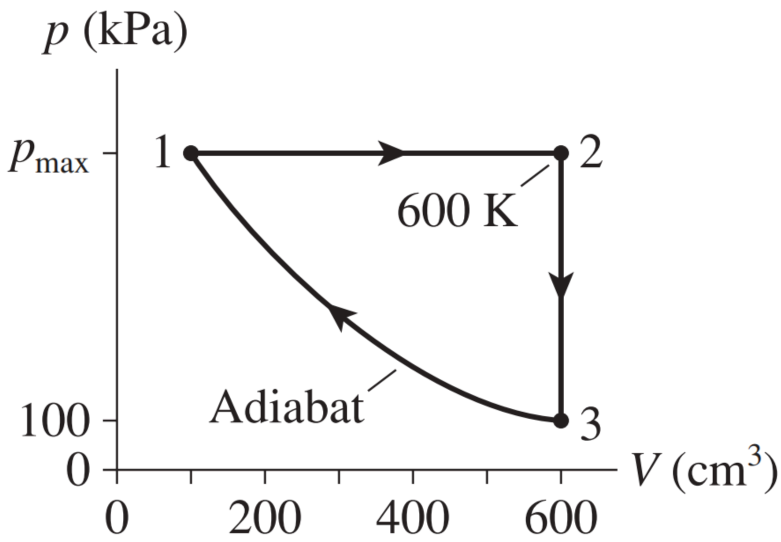
7 ✓

Question 1:



A heat engine using a monatomic gas follows the cycle shown in figure. What is the thermal efficiency of this heat engine? 27%

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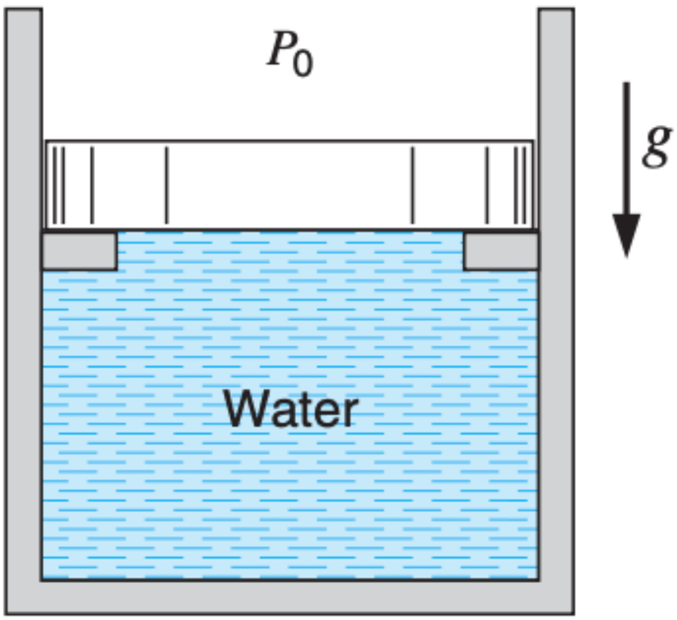
1. Isothermal Expansion (1→2)
   $P_1 = 600kPa$, volume expands from $V_1 = 200cm^3$ to $V_2 = 600cm^3$
   temperature change:
   $T_1 = 600K$. $T_2 = \frac{P_2V_2}{nR} = 1800K$
   Heat absorbed: (to be filled)
2. Isochoric Cooling (2→3)
   Volume held constant at $V_2 = 600cm^3$, pressure drops to $P_3 = 100kPa$
   Temperature change: $T_3 = \frac{P_3V_2}{nR} = 300K$
   Heat released (to be filled)
3. Isobaric Compression (3→1)
   Pressure held constant at $P_3 = 100kPa$, volume compress to $V_1 = 200cm^3$
   Temperature change: $T_1 = 600K$
   Heat absorbed (to be filled)

Thus: $W_{net} = W_1 + W_2 + W_3 = 240J - 40J + 0J = 200J$

Input heat: $Q_H = Q_1 + Q_3 = 598.6J + 149.7J \approx 748.3J$

Thermal Efficiency: $\eta = \frac{W_{net}}{Q_H} = \frac{200}{748.3} \approx 26.7\%$ around 27%

Question 2:



① $A = 0.01\,m^2$

② $F_g = m \cdot g = 100kg \times 9.81\,m/s^2 = 981N$

③ $F_{atm} = P_{atm} \cdot A = 100\,000\,Pa \times 0.01\,m^2 = 1000N$

④ $F_{total} = F_{atm} + F_g = 1981N$

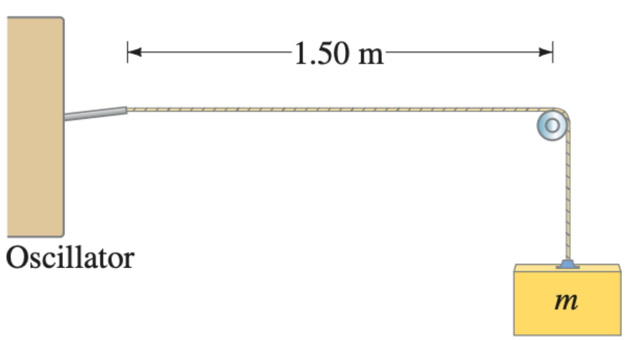
⑤ $P_{water} = \frac{F_{total}}{A} = \frac{1981N}{0.01\,m^2}$
$= 198.1\,kPa$

A piston/cylinder with a cross-sectional area of 0.01 \m^2\ has a piston mass of 100 kg resting on the stops, as shown in the figure. With an outside atmospheric pressure of 100 kPa, what should the water pressure be to lift the piston?

Question 3:

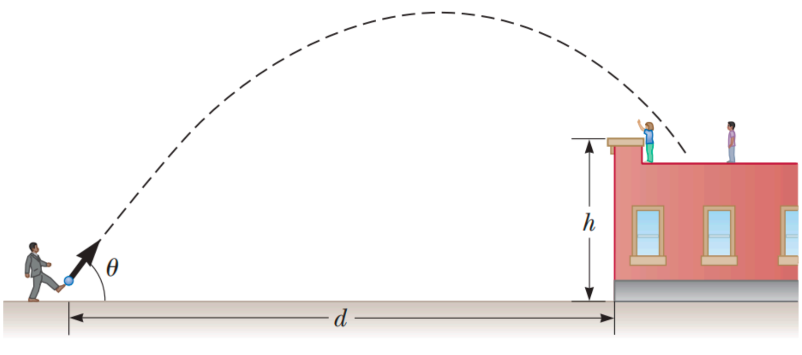
1. $\ell = \frac{\lambda}{2}$, $\lambda = 2\ell = 3.00m$
2. Wave speed $v = f \cdot \lambda = f \cdot 2\ell$
   $v = \sqrt{\frac{T}{\mu}}$, tension $T = mg$
3. $\sqrt{\frac{mg}{\mu}} = 2\ell f \Rightarrow mg = \mu \cdot (2\ell f)^2 \Rightarrow m = \frac{\mu \cdot (2\ell f)^2}{g}$
4. Linear density $\mu = 3.5 \times 10^{-4}\,kg/m$
   string length $\ell = 1.5m$
   Frequency $f = 60.0Hz$
   $g = 9.81m/s$

Thus: $m = \frac{3.5 \times 10^{-4} \cdot (2 \times 1.5 \times 60)^2}{9.81} = 1.16kg \approx 1.2kg$



One end of a horizontal string is attached to a small-amplitude mechanical 60.0\,\mathrm{Hz} oscillator. The string's mass per unit length is $3.5 \times 10^{-4}\,\mathrm{kg/m}$. The string passes over a pulley, a distance $\ell = 1.50\,\mathrm{m}$ away, and weights are hung from this end, figure.Assume the string at the oscillator is a node, which is nearly true. What mass m must be hung from this end of the string to produce one loop?

Question 4:



A playground is on the flat roof of a city school, $6.00 \mathrm{~m}$ above the street below as shown in figure. The vertical wall of the building is $h=7.00 \mathrm{~m}$ high, forming a 1-m-high railing around the playground. A ball has fallen to the street below, and a passerby returns it by launching it at an angle of $\theta=53.0^{\circ}$ above the horizontal at a point $d=24.0 \mathrm{~m}$ from the base of the building wall. The ball takes $2.20 \mathrm{~s}$ to reach a point vertically above the wall. Find the horizontal distance from the wall to the point on the roof where the ball lands.

A. $2.86 \mathrm{~m}$

B. $3.12 \mathrm{~m}$

C. $2.79 \mathrm{~m}$

D. $2.13 \mathrm{~m}$

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1. $V_{0x} = \frac{24}{2.20} \approx 10.909 \ m/s$

2. $7 = V_{0y} \cdot 2.20 - \frac{1}{2} \times 9.8 \times (2.20)^2 = 13.96 \ m/s$

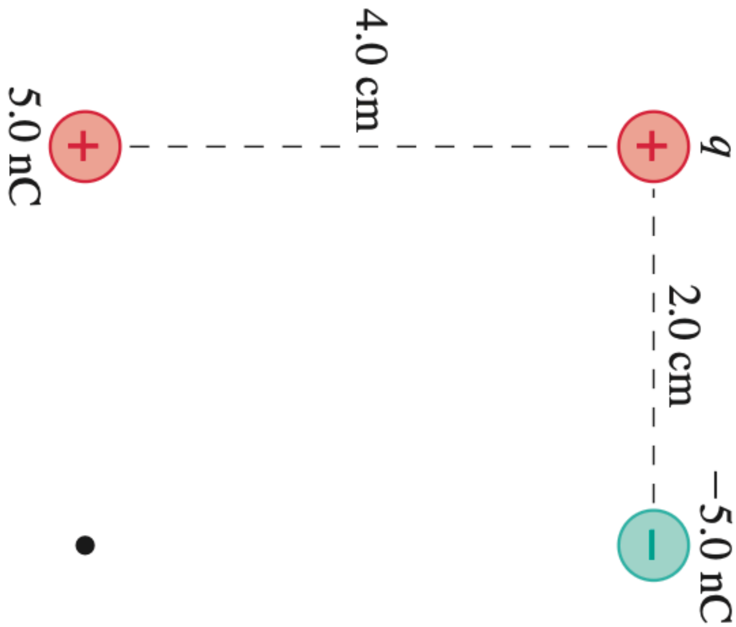
3. $y = x \tan\theta - \frac{g x^2}{2 V_{0x}^2}$

$6 = 1.327 x - \frac{9.8 x^2}{2 \times (10.909)^2}$

$x = 26.78 \ m$

$26.78 - 2.4 = 2.78 m$

Question 5:



The electric potential at the dot in figure is 3140 V. What is charge q? 14.23 nC

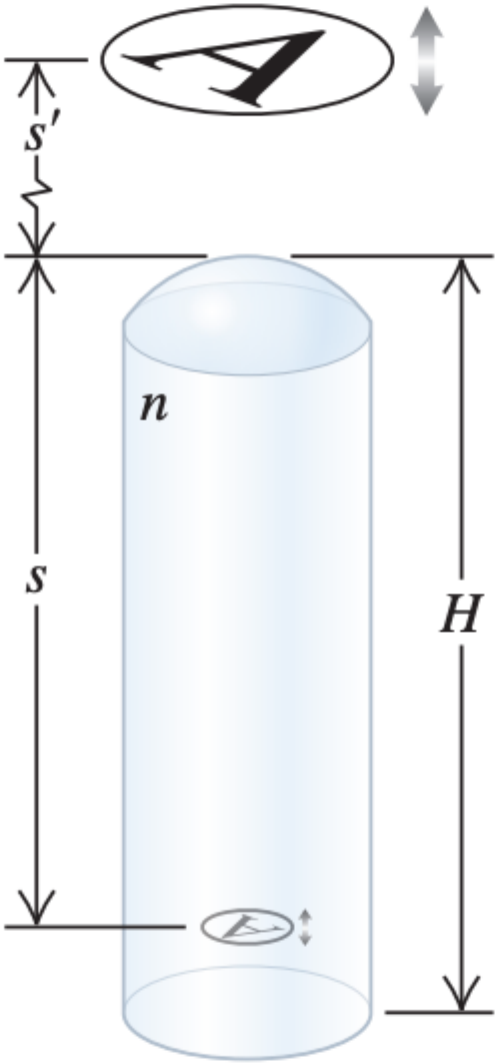
$V_{total} = k\left(\frac{5nC}{0.04m} + \frac{-5nC}{0.02m} + \frac{q}{r}\right)$

$V_1 + V_2 = 8.99\times10^9\left(\frac{5\times10^{-9}}{0.04} - \frac{5\times10^{-9}}{0.02}\right) = -1123.5V$

$\frac{kq}{r} = 3140 - (-1123.5) = 4263.5V$

$q = \frac{4263.5\times0.03}{8.99\times10^9} = 14.23nC$

Question 6:



A transparent cylindrical tube with radius $r = 1.50\,extcm$ has a flat circular bottom and a top that is convex as seen in figure. The cylinder is filled with quinoline, a colorless highly refractive liquid with index of refraction $n = 1.627$. Near the bottom of the tube, immersed in the liquid, is a luminescent LED display mounted on a platform whose height may be varied. The display is the letter A inside a circle that has a diameter of $1.00\,extcm$. A real image of this display is formed at a height s' above the top of the tube, as shown in figure. What is the diameter of the image when it is at its largest size?

1. $\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R} \rightarrow \frac{1.627}{s} + \frac{1}{s'} = 0.418\,cm^{-1}$

2. $m = -\frac{n_1 s'}{n_2 s} = -1.627 \cdot \frac{s'}{s}$

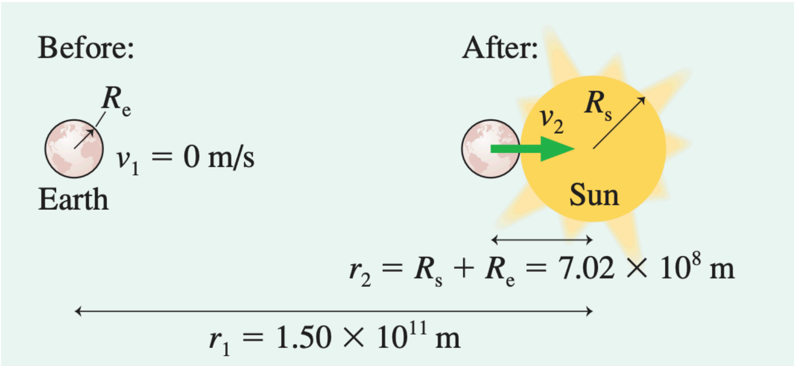
3. $f_1 = \frac{n_1 R}{n_2 - n_1} = 3.89\,m$

4. $s' = \frac{1}{0.418 - \frac{1.627}{4}} = 88.89\,cm \rightarrow |m| = 1.627 \times \frac{88.89}{4} = 36.1$

5. $f = \frac{n_2 R}{n_2 - n_1} = 2.39\,cm$

Diameter $= 1.627\,cm \approx 1.6\,cm$

Question 7:



Suppose the earth suddenly came to a halt and ceased revolving around the sun. The gravitational force would then pull it directly into the sun. What would be the earth's speed as it crashed?

1. Initial: Kinetic Energy $E_k = 0$

Gravitational potential energy: $U_1 = -\frac{GM_sM_e}{r_1}$

Final: K-E: $E_k = \frac{1}{2}M_e v^2$

G-P-E: $U_2 = -\frac{GM_sM_e}{r_2}$

2. $0 - \frac{GM_sM_e}{r_1} = \frac{1}{2}M_e v^2 - \frac{GM_sM_e}{r_2}$

$\Downarrow$

$V = \sqrt{2GM_s(\frac{1}{r_2} - \frac{1}{r_1})}$

3. $M_s = 1.989 \times 10^{30}$ kg

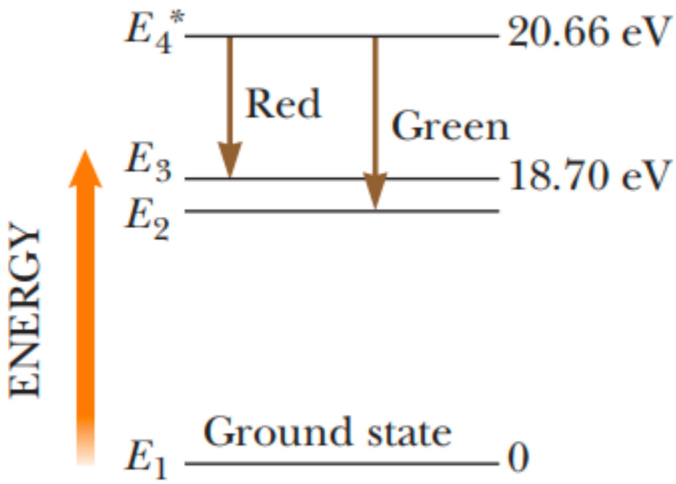
$r_1 = 1.5 \times 10^{11}$ m

$r_2 = 7.02 \times 10^{8}$ m

$\frac{1}{r_2} - \frac{1}{r_1} = 1.417 \times 10^{-9}\ m^{-1}$

$v = 6.13 \times 10^{5}$ m/s

Question 8:



A helium--neon laser can produce a green laser beam instead of a red one. Figure shows the transitions involved to form the red beam and the green beam. After a population inversion is established, neon atoms make a variety of downward transitions in falling from the state labeled E_4^* down eventually to level E_1 (arbitrarily assigned the energy $E_1 = 0$). The atoms emit both red light with a wavelength of 632.8 nm in a transition $E_4^* - E_3$ and green light with a wavelength of 543 nm in a competing transition $E_4^* - E_2$. What is the energy E_2? Assume the atoms are in a cavity between mirrors designed to reflect the green light with high efficiency but to allow the red light to leave the cavity immediately. Then stimulated emission can lead to the buildup of a collimated beam of green light between the mirrors having a greater intensity than that of the red light. To constitute the radiated laser beam, a small fraction of the green light is permitted to escape by transmission through one mirror. The mirrors forming the resonant cavity can be made of layers of silicon dioxide (index of refraction $n = 1.458$) and titanium dioxide (index of refraction varies between 1.9 and 2.6).

A. $24.16\ \mathrm{eV}$

B. $22.01\ \mathrm{eV}$

C. $15.31\ \mathrm{eV}$

D. $18.37\ \mathrm{eV}$

$E_{green} = \frac{hc}{\lambda}$

$E_4^* - E_2 = 2.285\,eV$

$E_2 = E_4^* - E_{green} = 18.375\,eV$

Question 9:

Figure was taken from the NIST Laboratory (National Institute of Standards and Technology) in Boulder, CO, $2.0\,\mathrm{km}$ from the hiker in the photo. The Sun's image was $15\,\mathrm{mm}$ across on the film. The Sun has diameter $1.4 \times 10^6\,\mathrm{km}$, and it is $1.5 \times 10^8\,\mathrm{km}$ away. Estimate the focal length of the camera lens.

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1. $\theta = \frac{D}{L}$.

$d = f \cdot \theta \longrightarrow f = \frac{d \cdot L}{D}$

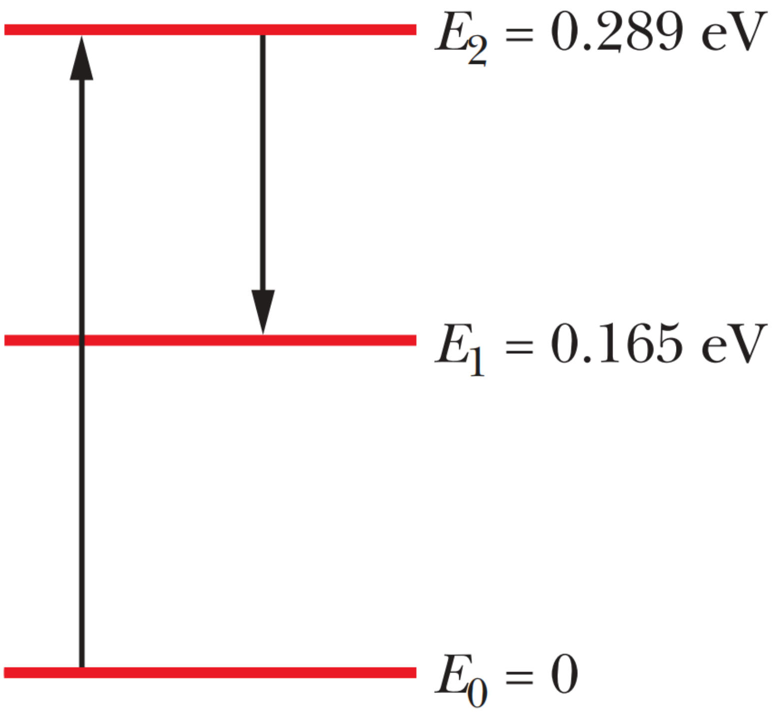
2. $D = 1.4 \times 10^6\,km = 1.4 \times 10^9\,m$

$L = 1.5 \times 10^8\,km = 1.5 \times 10^{11}\,m$

$d = 15\,mm = 0.015\,m$

$f = \frac{0.015m \times 1.5 \times 10^{11}m}{1.4 \times 10^9 m} = 1.607\,m \approx 1.6\,m$

Question 10:

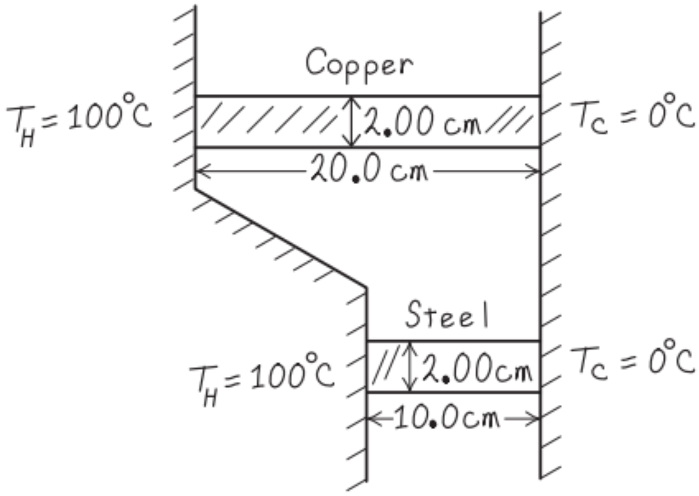


Where sunlight shines on the atmosphere of Mars, carbon dioxide molecules at an altitude of about $75\ \mathrm{km}$ undergo natural laser action. The energy levels involved in the action are shown figure; population inversion occurs between energy levels E_2 and E_1. At what wave-length does lasing occur?

1. $\Delta E = E_2 - E_1 = 0.289\,eV - 0.165\,eV = 0.124\,eV$

2. $\lambda = \frac{1.24}{0.124} = 10.0\,\mu m$

Question 11:



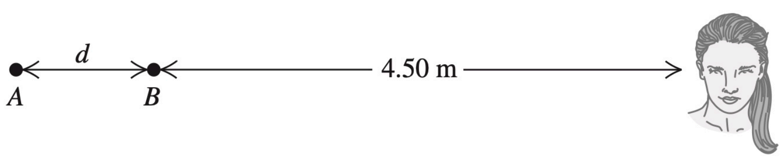
1. Steel rod : $\frac{Q}{t} = \frac{50 \times 0.0004 \times 100}{0.10} = 20W$

2. Copper rod $\frac{Q}{t} = \frac{385 \times 0.0004 \times 100}{0.20} = 77W$

$77 + 20 = 97W$

A steel bar 10.0 \, \mathrm{cm} long is welded end to end to a copper bar 20.0 \, \mathrm{cm} long. Each bar has a square cross section, 2.00 \, \mathrm{cm} on a side.Suppose the two bars are separated. One end of each bar is kept at 100^\circ \mathrm{C} and the other end of each bar is kept at 0^\circ \mathrm{C}. What is the total heat current in the two bars?

Question 12:



Small speakers A and B are driven in phase at $725\,\mathrm{Hz}$ by the same audio oscillator. Both speakers start out $4.50\,\mathrm{m}$ from the listener, but speaker A is slowly moved away (\textbf{figure}). At what distance d will the sound from the speakers first produce destructive interference at the listener's location?

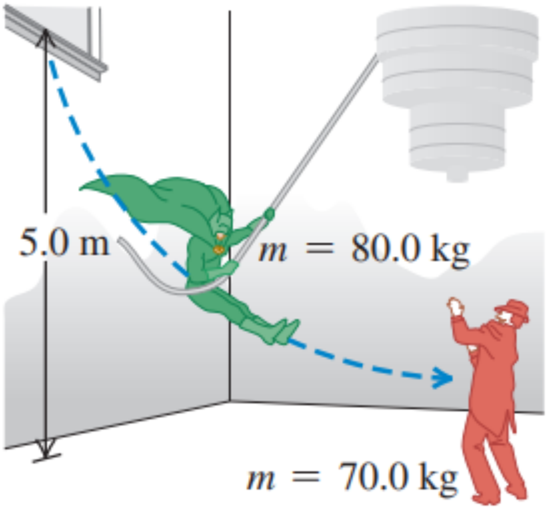
$v = 343\ m/s$ $f = 725Hz$

$\lambda = \frac{v}{f} = \frac{343}{725} = 0.473m$

$\Delta = \frac{\lambda}{2}$, $d - 4.50m$

$d - 4.50m = \frac{0.473}{2} \Rightarrow d \approx 4.5 + 0.2365 \approx 4.74m$

Question 13:



A movie stuntman stands on a window ledge above the floor as shown in figure. Grabbing a rope attached to a chandelier, he swings down to grapple with the movie's villain, who is standing directly under the chandelier. (Assume that the stuntman's center of mass moves downward 5.0 m. He releases the rope just as he reaches the villain.) If the coefficient of kinetic friction of their bodies with the floor is \\(\\mu_k = 0.250\\), how far do they slide?

A. 4.6m

B. 5.7m

C. 4.2m

D. 4.8m

1. $U = mgh = 80.0kg \times 9.81 m/s^2 \times 5.0m = 3924 J$

$V = \sqrt{\frac{2U}{m}} = \sqrt{\frac{2\times 3924}{80.0}} = 9.9 m/s$

2. $m_{total} = 80 + 70 = 150.0kg$

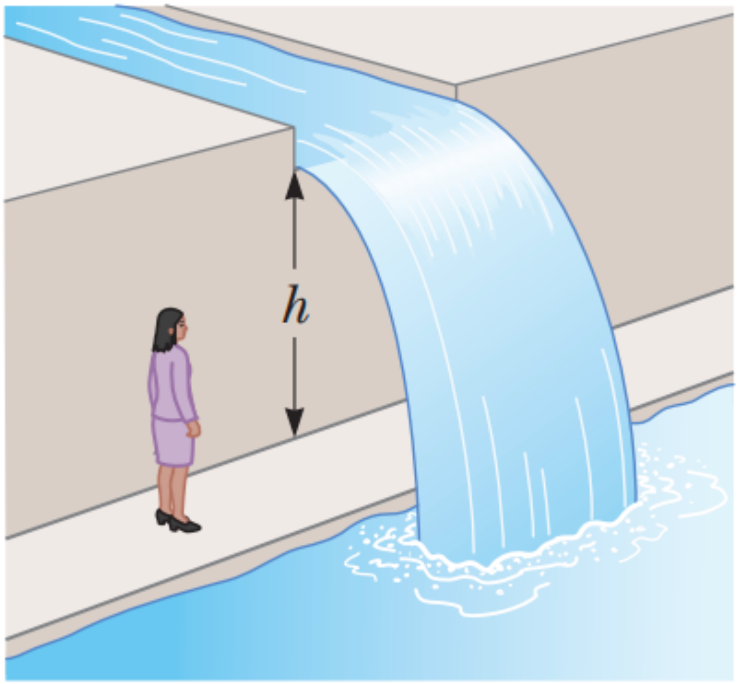
$V' = \frac{m_{stunt} \cdot V}{m_{total}} = \frac{80.0 \times 9.9}{150.0} \approx 5.28 m/s$

3. $KE = \frac{1}{2} m_{total} V'^2 = \frac{1}{2} \times 150.0 \times (5.28)^2) \approx 2090.85 J$

$f = \mu_k \cdot m_{total} \cdot g = 0.250 \times 150.0 \times 9.81 \approx 367.5N$

$d = \frac{KE}{f} = \frac{2090.85}{367.5} \approx 5.69 m$

Question 14:



A landscape architect is planning an artificial waterfall in a city park. Water flowing at $1.70\ \mathrm{m/s}$ will leave the end of a horizontal channel at the top of a vertical wall $h = 2.35\ \mathrm{m}$ high, and from there it will fall into a pool as shown in figure. To sell her plan to the city council, the architect wants to build a model to standard scale, which is one-twelfth actual size. How fast should the water flow in the channel in the model?

A. $0.325\ \mathrm{m/s}$

B. $0.120\ \mathrm{m/s}$

C. $0.491\ \mathrm{m/s}$

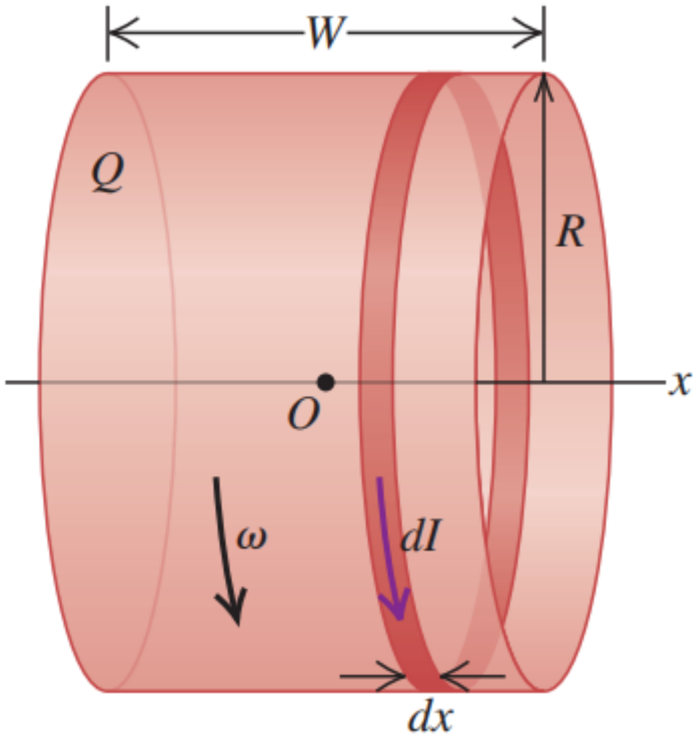
D. $0.212\ \mathrm{m/s}$

1. $\frac{V_{model}}{\sqrt{gL_{model}}} = \frac{V_{prototype}}{\sqrt{gL_{model}}} \Rightarrow V_{model} = V_{prototype} \cdot \sqrt{\frac{L_{model}}{L_{prototype}}}$

2. Scale factor $= \frac{1}{12}$

$V_{model} = 1.70\,m/s \cdot \sqrt{\frac{1}{12}} = 0.491\ m/s$

Question 15:



A cylindrical shell with radius R and length W carries a uniform charge Q and rotates about its axis with angular speed ω. The center of the cylinder lies at the origin O and its axis is coincident with the x-axis.

$$\sigma = \frac{Q}{2\pi R W}$$

$$K = \sigma v = \frac{Q}{2\pi R W} \cdot \omega R = \frac{Q\omega}{2\pi W}$$

$$I = K \cdot W = \frac{Q\omega}{2\pi}$$

$$m = I \cdot \pi R^2 = \frac{Q\omega}{2\pi} \cdot \pi R^2 = \frac{1}{2} Q\omega R^2$$

Question 16:

Police radar detects the speed of a car as shown in figure. Microwaves of a precisely known frequency are broadcast toward the car. The moving car reflects the microwaves with a Doppler shift. The reflected waves are received and combined with an attenuated version of the transmitted wave. Beats occur between the two microwave signals. The beat frequency is measured. What beat frequency is measured for a car speed of $30.0\,\mathrm{m/s}$ if the microwaves have frequency $10.0\,\mathrm{GHz}$?

$f' = f \cdot \frac{c+v}{c}$

$f'' = f' \cdot \frac{c}{c-v} = f \cdot \frac{c+v}{c-v}$

$\Delta f = f'' - f = f \cdot \frac{2v}{c-v}$

when $v \ll c$: $\Delta f \approx \frac{2vf}{c}$

$\Delta f \approx \frac{2\times 30.0 \times 10.0 \times 10^9}{3\times 10^8} = 2.00\,\mathrm{kHz}$

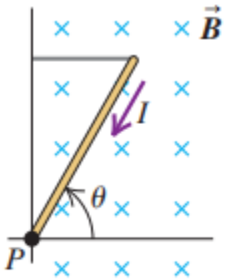
A. $2.80\,\mathrm{kHz}$

B. $1.80\,\mathrm{kHz}$

C. $1.50\,\mathrm{kHz}$

D. $2.00\,\mathrm{kHz}$

Question 17:



The lower end of the thin uniform rod is attached to the floor by a frictionless hinge at point P. The rod has mass $0.0840\,\mathrm{kg}$ and length $18.0\,\mathrm{cm}$ and is in a uniform magnetic field $B = 0.120\,\mathrm{T}$ that is directed into the page. The rod is held at an angle $heta = 53.0^\circ$ above the horizontal by a horizontal string that connects the top of the rod to the wall. The rod carries a current $I = 12.0\,\mathrm{A}$ in the direction toward P. Calculate the tension in the string.

$mg = 0.0840\,kg \times 9.81\,m/s^2 = 0.824\,N.$

$\tau_g = mg \cdot \frac{L}{2} \cos\theta = 0.824 \times 0.09 \cdot \cos 53^\circ \approx 0.0445$

$F = I \cdot L \cdot B = 0.2592\,N$

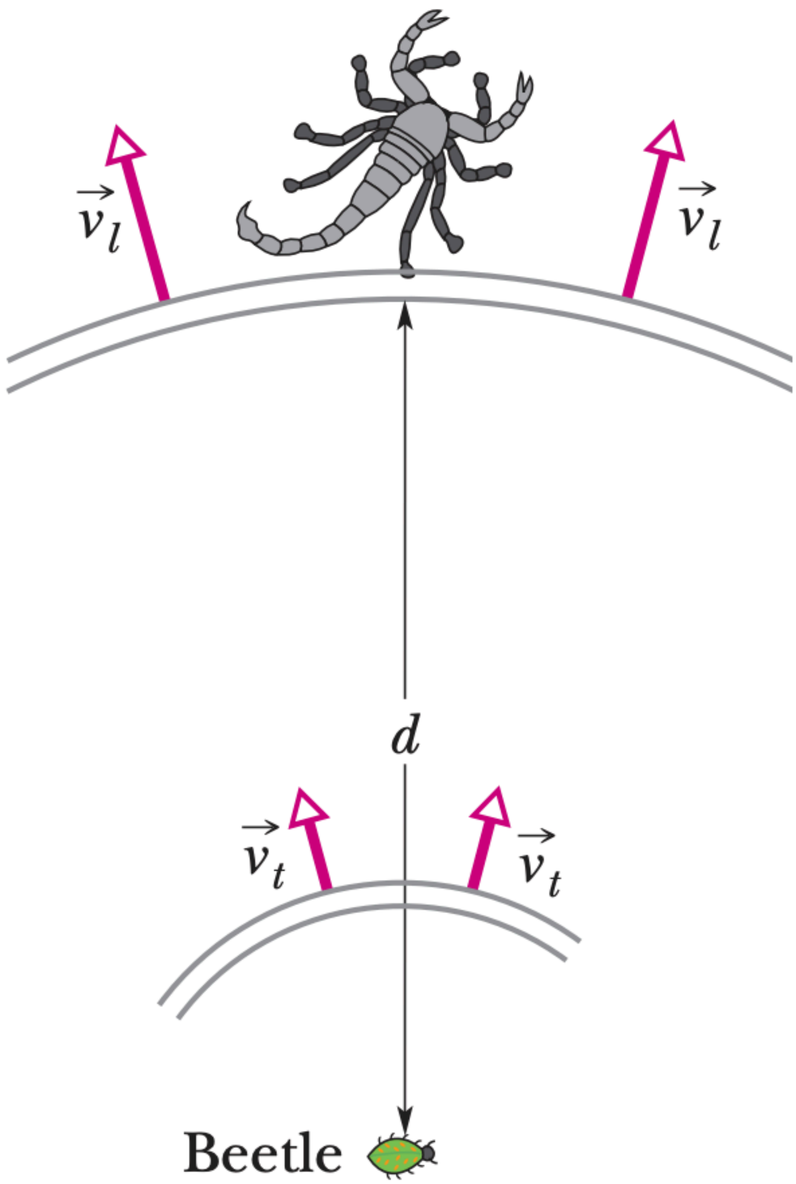
$\tau_F = F \cdot \frac{L}{2} \sin\theta \approx 0.0187$

$\tau_T = T \cdot L \sin\theta \approx T \cdot 0.1437$

$\tau_T = \tau_g + \tau_F \Rightarrow T \cdot 0.1437 = 0.0445 + 0.0187$

$T = 0.440\,N$

Question 18:



A sand scorpion can detect the motion of a nearby beetle (its prey) by the waves the motion sends along the sand surface. The waves are of two types: transverse waves traveling at $v_t = 50\,\mathrm{m/s}$ and longitudinal waves traveling at $v_l = 150\,\mathrm{m/s}$. If a sudden motion sends out such waves, a scorpion can tell the distance of the beetle from the difference Δt in the arrival times of the waves at its leg nearest the beetle. If $\Delta t = 4.0\,\mathrm{ms}$, what is the beetle's distance?

$t_t = \frac{d}{v_t}$, $t_l = \frac{d}{v_l}$

$\Delta t = t_t - t_l = \frac{d}{50} - \frac{d}{150}$

$= 4.0 \times 10^{-3}\,s \Rightarrow \frac{3d-d}{150} = 0.004$ $\quad d = 0.30m.$